POTENTIAL OVERLOOKED ANALOGUES TO THE INDIAN OCEAN TSUNAMI IN THE WESTERN AND SOUTHWESTERN PACIFIC

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ABSTRACT

In a more detailed examination of subducting margins of the Western and Southwestern Pacific, segments are found that are similar to the segment along the Indian Ocean that ruptured on 26 December 2004. Similarities are found in terms of hypocenter distributions and historical seismicity. The largest reported moment magnitudes in the Western and Southwestern Pacific since 1900 were an 8.5, an 8.4, and an 8.3. Should any substantially larger earthquakes occur along these segments or elsewhere in the Western or Southwestern Pacific, Civil Defense agencies in the Hawaiian Islands should be aware of any possible inadequacies in existing evacuation procedures for western and southern shores.

INTRODUCTION

In an earlier report (Walker, 2005) comparisons were made between the seismic histories of the eastern margin of the Indian Ocean and subducting margins of the Western and Southwestern Pacific. From 1900 through 25 December 2004, the largest moment magnitude (Mw) earthquakes at depths of 100 kilometers or less throughout the Western and Southwestern Pacific were an 8.5, an 8.4, and an 8.3. For the same time period and depth range in other areas of the Pacific, the largest values were a 9.6, 9.2, and 9.0. Along the eastern margin of the Indian Ocean for the same time period and depth range, the largest values were two 7.9's. For specific portions of the circum-Pacific arc from Japan southward to New Guinea and eastward from New Guinea to Samoa, seismic histories similar to the eastern margin of the Indian Ocean were found.

Using data prior to 26 December 2004, earth scientists could have concluded that significant ocean-wide tsunamis in the Indian Ocean were not a likely occurrence. Facing other serious political, social, and economic issues, public officials in countries surrounding the Indian Ocean could easily use the historical record prior to 26 December 2004 as justification for assigning a low priority to concerns for a devastating ocean-wide tsunami. In this report a more detailed analysis of specific segments of the circum-Pacific arc to the west and southwest of the Hawaiian Islands are investigated as possible analogues to the eastern margin of the Indian Ocean. Such investigations should be of interest because, as in the Indian Ocean, no significant Pacific-wide tsunamis (Table 1) are known to have been generated from that portion of the circum-Pacific arc extending from south of Japan to Samoa. Therefore, earth scientists might similarly conclude that such areas are unlikely source locations for significant ocean-wide tsunamis; and public officials could assign a low priority to concerns for a devastating ocean-wide tsunami from those regions.

ANALYSIS

Hypocenter distributions (i.e., epicenters for two depth ranges) for the eastern margin of the Indian Ocean are shown in Figure 1. These data are taken from the U.S. Geological Survey's National Earthquake Information Center (NEIC) on-line data base for magnitude 5.5 or greater earthquakes from 1973 through 25 December 2004. [The magnitude range and time period used provides for reasonably accurate hypocenter determinations.] Also, since only shallow or intermediate focal depth earthquakes have generated significant ocean-wide tsunamis (Table 1), only hypocenters for focal depths of 70 kilometers or less are shown in Figure 1. In many areas the shallower earthquakes (i.e., 33 km or less) are distributed across the subducting margin on either side of the deeper intermediate events (i.e., 70 km to 33 km). The frequency distribution of moment magnitudes from 1900 through 25 December 2004 for earthquakes with focal depths of 70 kilometers or less in the area shown in Figure 1 is given in Table 2. The largest earthquake in the 104 years prior to the 9.0 Mw event (NEIC reported Harvard solution) on 26 December 2004 was a 7.9.

Figure 2 provides additional evidence that significant tsunamigenic earthquakes generally have focal depths of 70 kilometers or less. Figure 2 is a hypocenter plot for the 48 hour time period from 25 December 2004 through 26 December 2004. The depth range for this NEIC data search is 0 to 800 kilometers and the magnitude range is 1 to 10. In separate NEIC listings of these 287 earthquakes (not shown), none were found for the 25th of December. The first earthquake to appear on the list was the 9.0 Mw 30 kilometer depth event at 00 hours and 58 minutes on the 26th followed by 286 earthquakes in the next 23 hours. None of these had a focal depth in excess of 70 kilometers, the greatest reported depth being 61 kilometers. These data indicate substantial decoupling between deeper structures and the displacements occurring at depths of 70 kilometers or less. Decoupling is further indicated by a longer term analysis of NEIC data. In the month prior to the 26th, four earthquakes with depths in excess of 70 kilometers were found. In the month including and following the 26th, two earthquakes with depths in excess of 70 kilometers were found.

An overview of subducting margins throughout the Western and Southwestern Pacific is provided by the hypocenter distributions shown in Figure 3. Hypocenter distributions for a specific segment south of Japan are shown in Figure 4. In many areas shallower earthquakes are distributed across the subducting margin on either side of the intermediate events. The distribution of moment magnitudes from 1900 through 2005 is shown in Table 2. The largest values are two 8.1's. [It should be noted that the Sanriku earthquake of 1933 occurred to the north of the area shown in Figure 4 at 39.2N and 144.5E. This earthquake had a magnitude of 8.4 and a maximum reported runup in the Hawaiian Islands of 3.3 meters (Table 1).]

Hypocenter distributions in the Solomon Islands are shown in Figure 5. Again in many areas shallower earthquakes are distributed across the subducting margin on either side of the intermediate depth events. From 1900 through 2005 the largest earthquake is an 8.1 (Table 2). [Note that in some regions, islands just to the north of possible source locations might impede the transmission of tsunamis into the Pacific.]

Hypocenter distributions for Vanuatu are shown in Figure 6. Again in many areas shallower earthquakes are distributed across the subducting margin on either side of the intermediate depth events. From 1900 through 2005 the largest earthquakes were two 7.8's (Table 2). [Note that numerous island chains (the Marshall, Gilbert, Phoenix, Tuvalu, Kiribati, and Samoa islands) are in the paths of potential tsunamis traveling from either Vanuatu or the Solomon Islands to Hawaii. These islands and their shallower waters may or may not absorb significant amounts of tsunamigenic energy.]

IMPLICATIONS FOR THE HAWAIIAN ISLANDS

In terms of the frequency of large earthquakes, hypocenter distributions, and the extent of apparently contiguous segments (on the order of 1000 km), there are no outstanding distinctions between the segments shown for the Western and Southwestern Pacific and the segment in the Indian Ocean that ruptured on 26 December 2004. Although there may be other factors in assessing the risks of a 9.0+Mw earthquake in the Western or

Southwestern Pacific, the simple analysis presented here should be sufficient for Civil Defense agencies to urgently consider their preparedness for such an event – lest they fall victim to some of the same human failings that contributed to the Asian tsunami disasters. At present, tsunami preparedness in the Hawaiian Islands is based in large part on historical runup data from large tsunamis originating in the North Pacific and South America. Measured runups of 5 to 16 meters for the world's largest recorded earthquakes (9.6 Chile, 9.2 Alaska, and 9.0 Kamchatka; Table 1) and the anomalous 1946 Aleutian tsunami most likely represent worst case scenarios for northern and eastern shores of the Hawaiian Islands. As such, Civil Defense may have enough data to prepare for future tsunamis striking those areas. Since the largest tsunami to strike the Hawaiian Islands from the Western or Southwestern Pacific could be considered to be the tsunami generated by the previously mentioned 8.4 Sanriku earthquake of 1933 (actually located somewhat to the northwest of Hawaii), the following questions need to be asked:

> " Just as the 5 to 16 meter runups on the northern and eastern shores of the Hawaiian Islands were generated by the 9.0+ earthquakes in Chile, Alaska, and Kamchatka, could 9.0+ earthquakes in the Western or Southwestern Pacific generate 5 to 16 meter runups on the southern and western shores of the Hawaiian Islands? If so, is the State prepared for 5 to 16 meter runups in those areas?"

[A possible consideration in answering these questions is the fact that all known 9.0+ earthquakes (i.e., the Chile, Alaska, Kamchatka, and 26 December 2004 Indonesia earthquakes) have generated ocean-wide tsunamis of at least 5 meters or more. The only other suspected 9+ Mw earthquakes prior to 1900 are the Cascadia earthquake of 1700 that may have generated a 3 meter tsunami in Japan ("USGS Historic Worldwide Earthquakes" on-line data) and the 1868 Chile earthquake that generated a 4.5 meter tsunami in Hawaii ("Historical Tsunami Database for the Pacific, 47 B.C. – 2001" on-line data).]

CONCLUSIONS

Numerical modeling of tsunamis generated by potential 9.0+ earthquakes for the segments suggested here or for other locations in the Western and Southwestern Pacific is needed to determine the extent of possible inundation in the Hawaiian Islands – especially along western and southern shores. Implications elsewhere throughout the Pacific should also be investigated.

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TABLE 1

SIGNIFICANT PACIFIC WIDE TSUNAMIS
1900 – 2005

Year	Source Location	Magnitude (Mw)	Depth (km)	Runup (m)
1906	Ecuador	8.5	25	1.8
1906	Chile	8.5	25	3.6
1918	Kurils	8.2	25	1.5
1922	Chile	---	25	2.1
1923	Kamchatka	8.5	40	6.1
1933	Japan	8.4	25	3.3
1946	Aleutians	8.0	50	16.4
1952	Kamchatka	9.0	40	9.1
1957	Aleutians	8.6	33	16.1
1960	Chile	9.6	60	10.7
1964	Alaska	9.2	23	4.9
1965	Aleutians	8.7	36	1.1

Significant tsunamis are considered to be those originating on the margins of the Pacific with runups of 1 meter or more in the Hawaiian Islands. Runups listed are the highest reported values from Lander and Lockridge (1989) and Walker (2000). Moment magnitudes are taken from Pacheco and Sykes (1992) using $Mw = [\log(Mo) – 9.1] / 1.5$ (Hanks and Kanamori, 1979). Depths are taken from the U.S. Geological Survey's National Earthquake Information Center (NEIC) on-line data base. The only other earthquake generating runups of 1 meter or more at ocean-wide distances having a reliable focal depth determination is the 9.0 Mw 26 December 2004 Indonesian earthquake with an estimated depth of 30 kilometers (NEIC on-line data).

TABLE 2

MOMENT MAGNITUDES FOR SEGMENTS OF SUBDUCTING MARGINS FOR LOCAL DEPTHS OF 70 KILOMETERS OR LESS

Moment Magnitude	Region			
	Indonesia	S. of Japan	Solomons	Vanuatu
7.0	X		XX	XXXX
7.1	X		XX	XXX
7.2		X	XXXX	XXXX
7.3	XXX		XX	X
7.4	XXX	XXXX	XX	
7.5	XX	XX	XXXX	X
7.6			XXXXX	
7.7	X		XX	XX
7.8	X		XXX	XX
7.9	X	X		
8.0				
8.1		XX	X	
8.2				

The time period for the Indonesia data is 1900 through 25 December 2004. The time period for the data used in other segments is 1900 through 2005. Moment magnitudes through 1989 are taken from Pacheco and Sykes (1992) and Hanks and Kanamori (1979) as indicated for Table 1. After 1989 the values used are the Harvard solutions from the NEIC on-line data base.

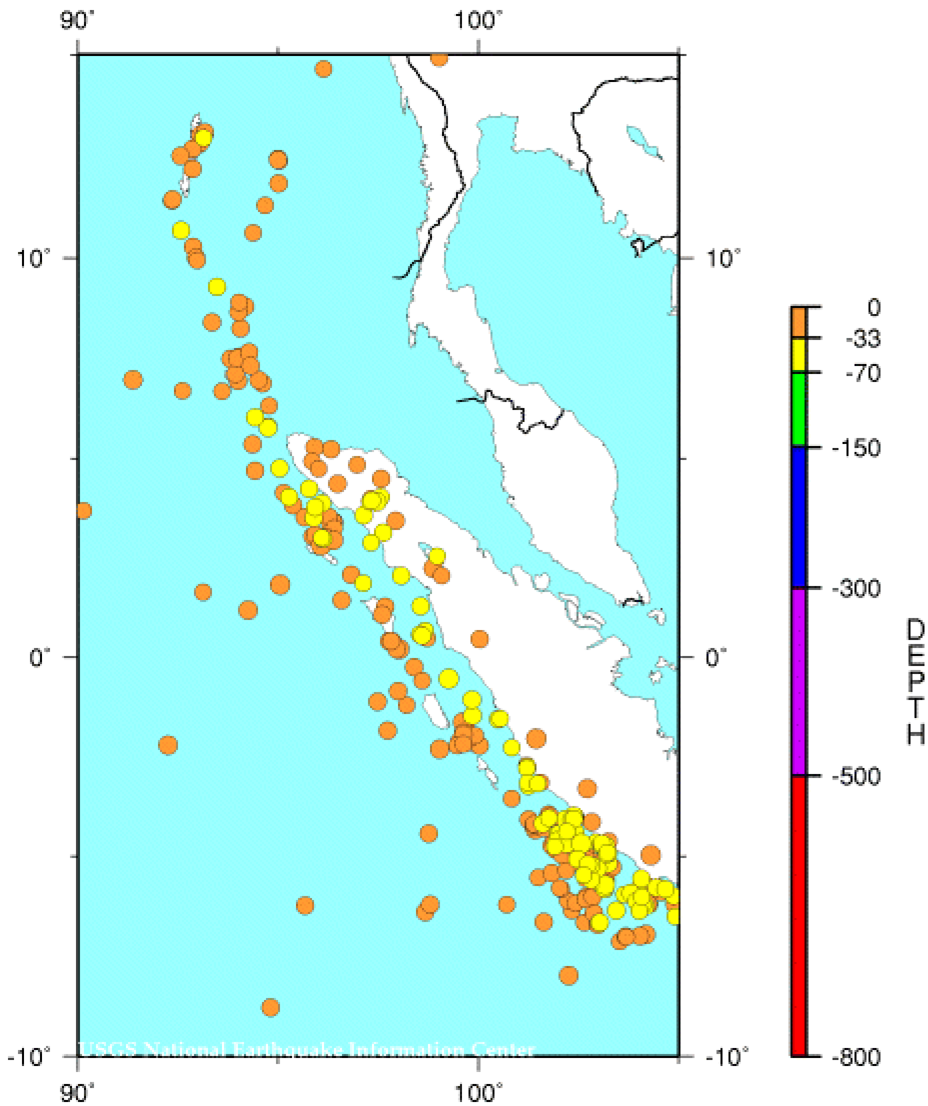

Figure 1. Hypocenter distributions for the eastern margin of the Indian Ocean for focal depths of 70 kilometers or less and magnitudes (i.e., any values: Mw, Ms, mb, or Me) of 5.5 or greater from 1973 through 25 December 2004 using the U.S. Geological Survey's National Earthquake Information Center (NEIC) on-line data base.

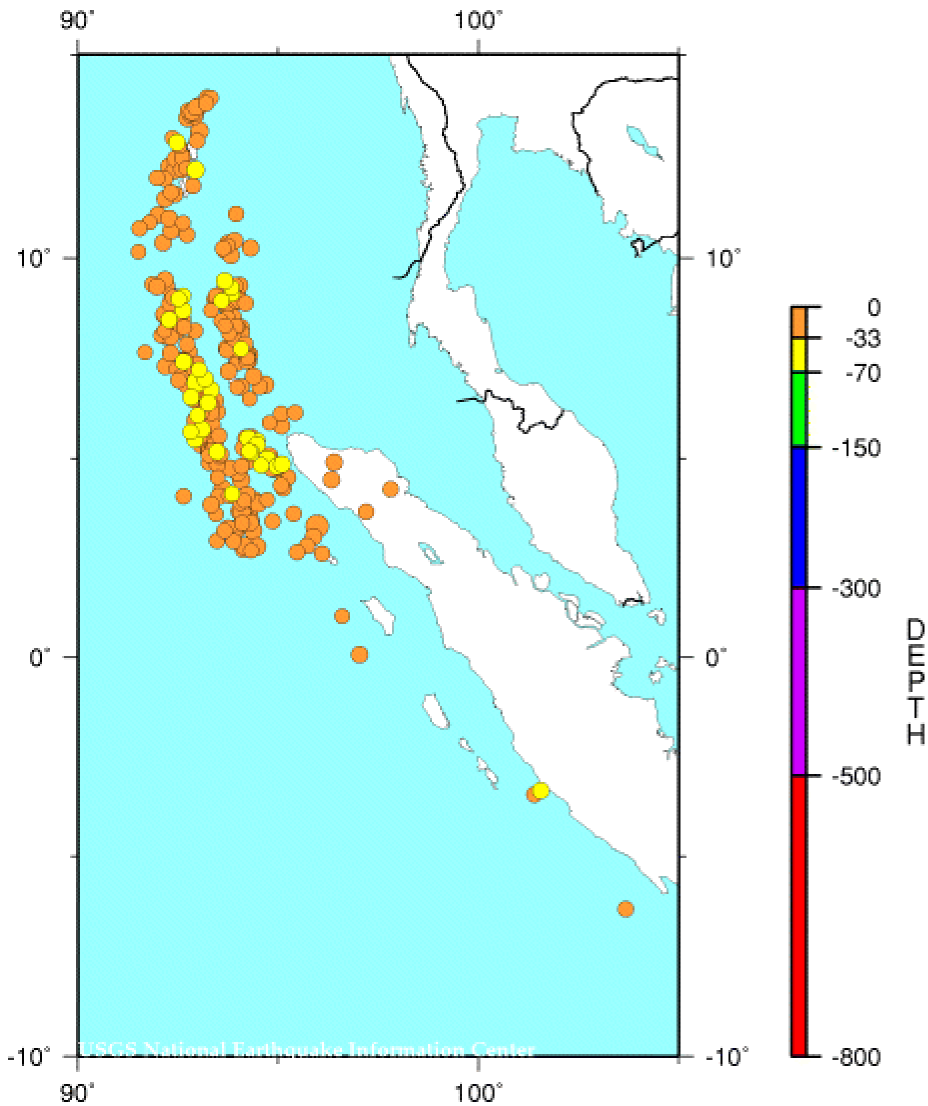

Figure 2. Hypocenters for the eastern margin of the Indian Ocean for all focal depths and magnitudes for the 48 hours from 25 December 2004 through 26 December 2004 using NEIC on-line data.

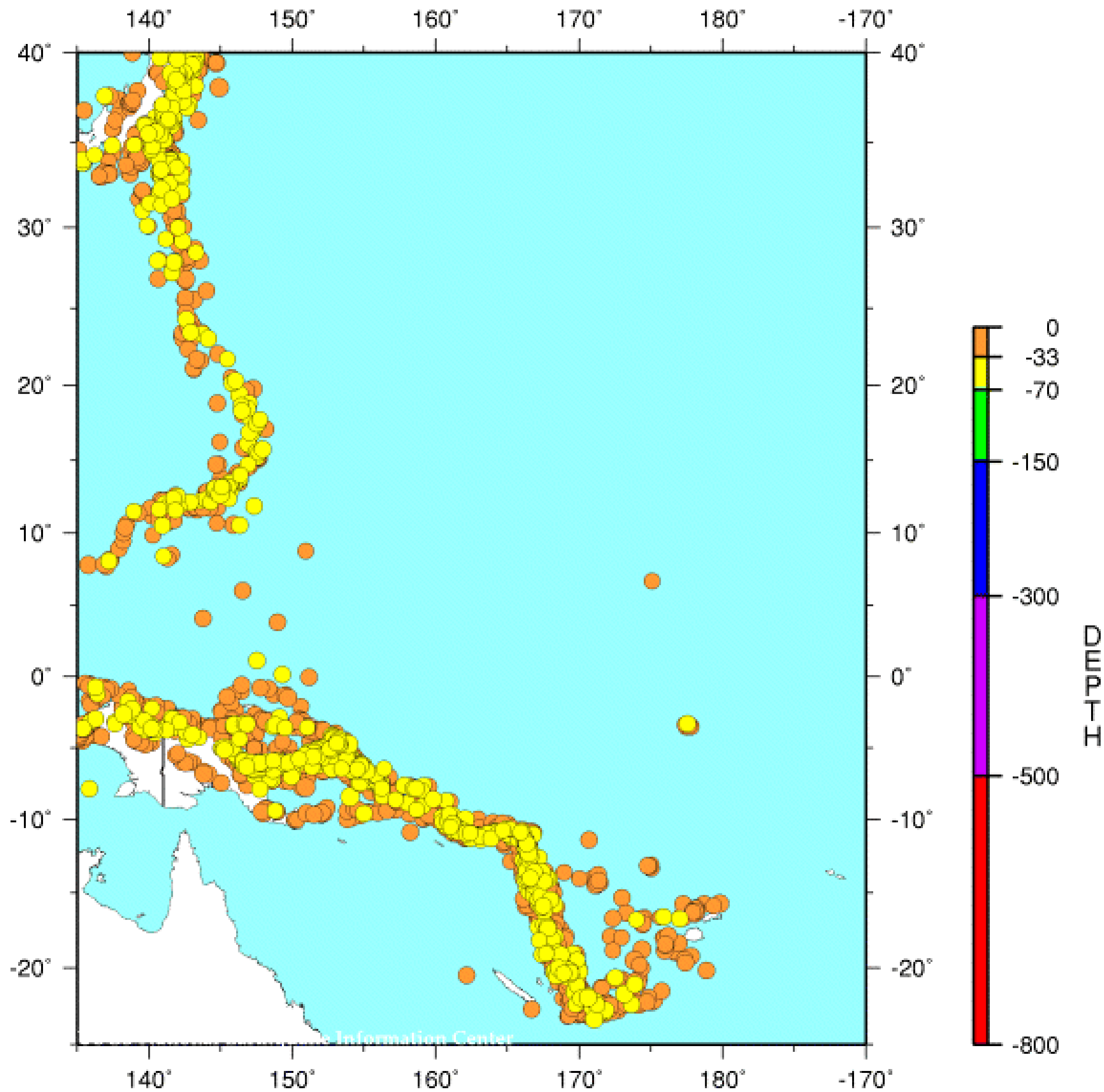

Figure 3. Hypocenters for the Western and Southwestern Pacific for focal depths of 70 kilometers or less and magnitudes of 5.5 or greater from 1973 through 2005 using NEIC on-line data. Similarly restricted NEIC on-line data are shown in Figures 4, 5, and 6.

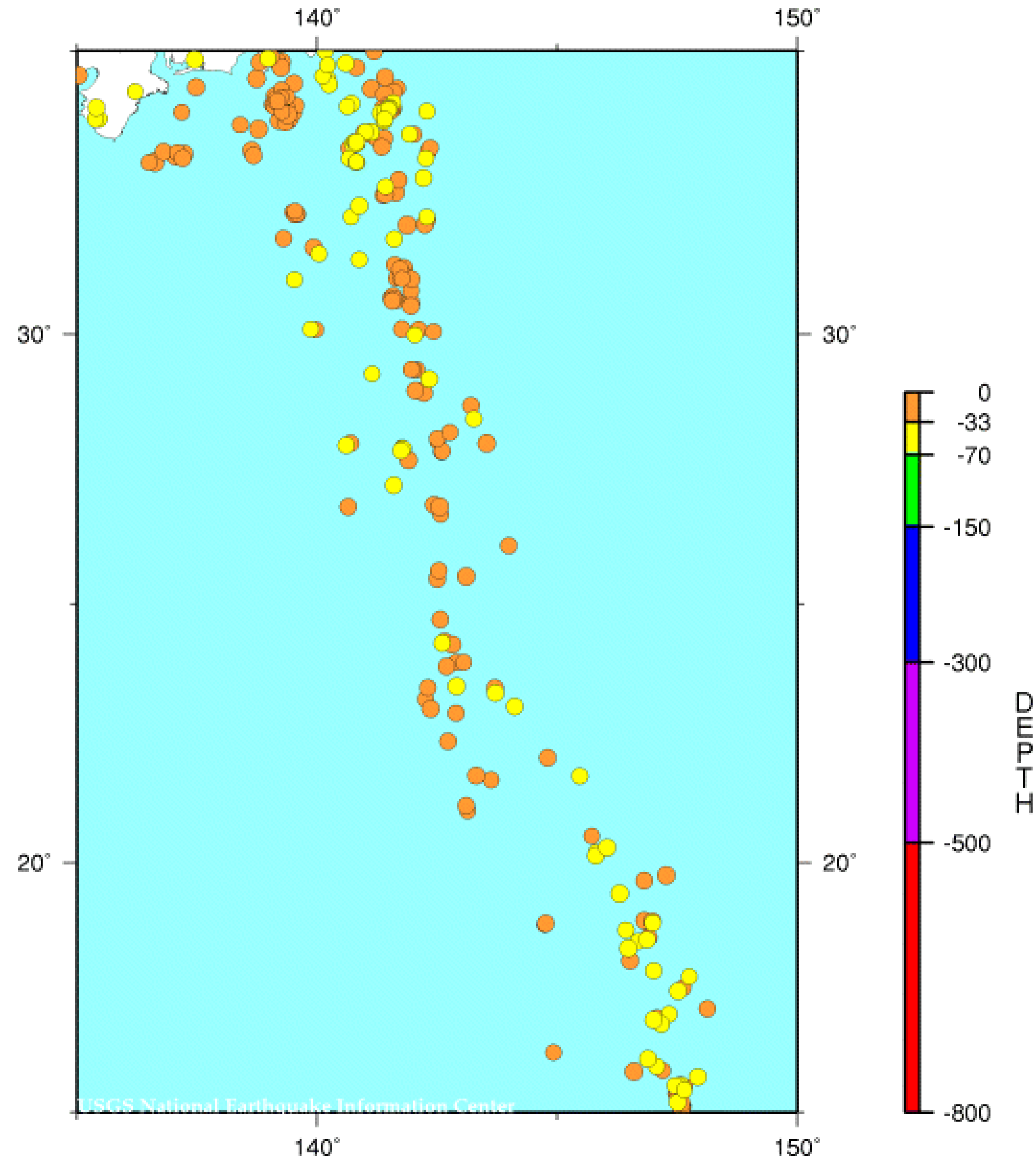

Figure 4. Hypocenters for a segment of the circum-Pacific arc from south of Japan to north of Guam.

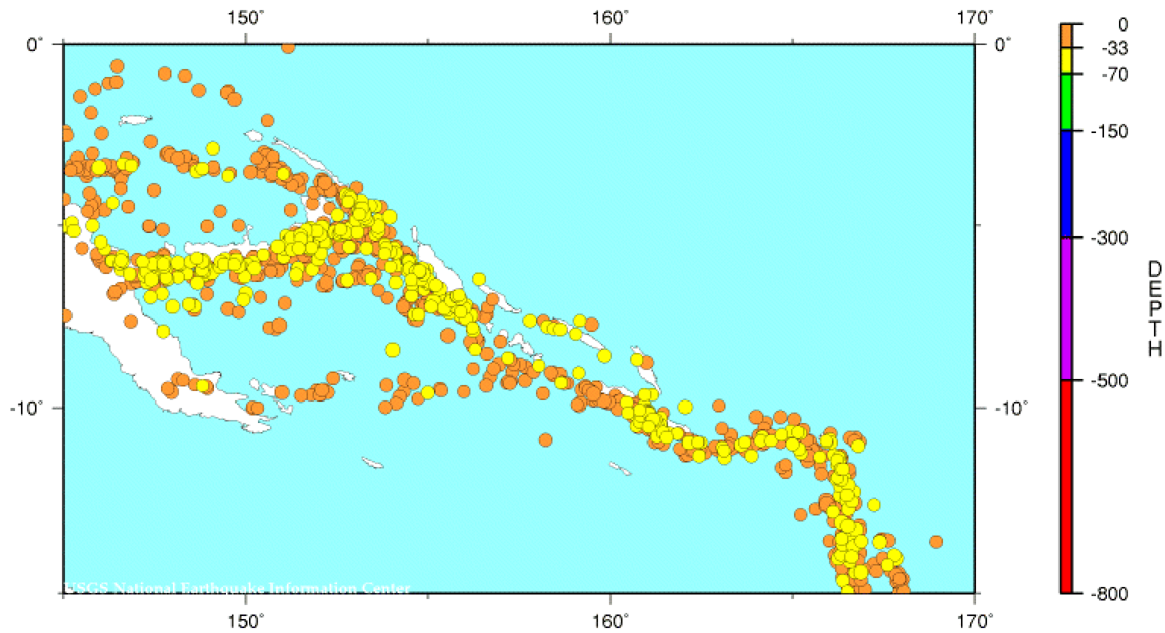

Figure 5. Hypocenters for the Solomon Islands.

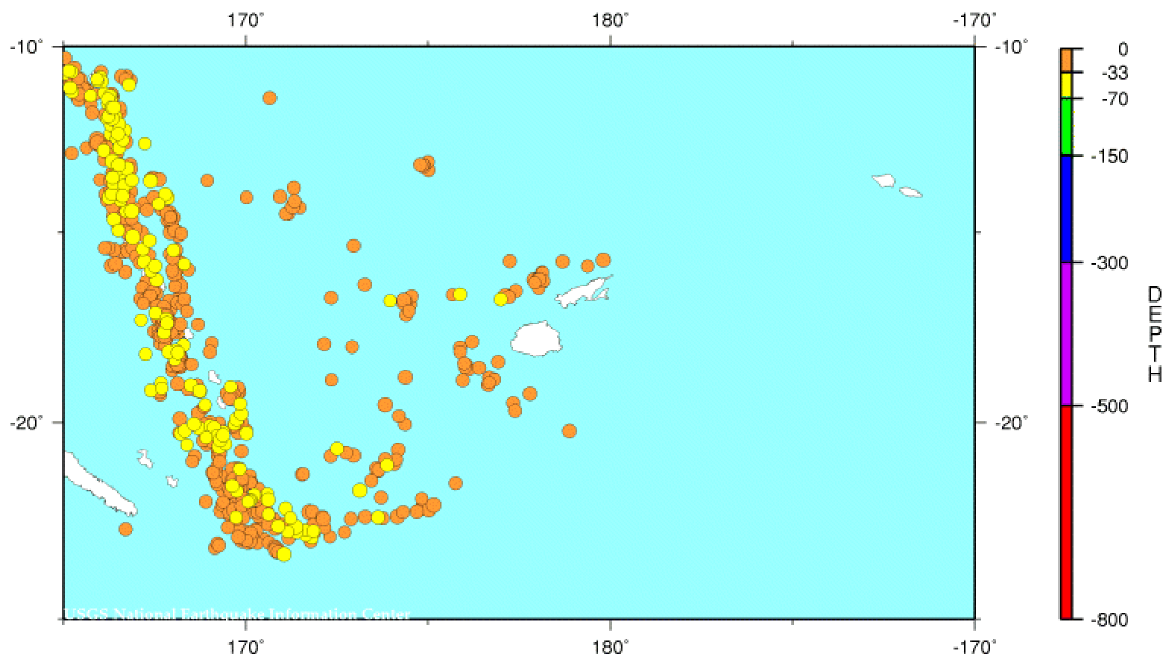

Figure 6. Hypocenters for Vanuatu.